# OPTICAL FIBER BASED THERMOMETRY SYSTEM FOR A HYPERTHERMIA LABORATORY

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***Abstract* – The development and construction of a thermometry system based on optical fiber sensors is presented. This system is used in a laboratory of experimental hyperthermia to characterize the distribution of temperature on a substitute material of biological tissue (phantom), when it is subjected to controlled electromagnetic or ultrasonic radiations. The experiments are carried out inside an anechoic chamber. The temperature sensors were developed based on plastic optical fibers that work under the principle of evanescent sensors. Its presence in the phantom doesn't disturb the electromagnetic fields. The sensors are positioned inside the phantom by means of a system of automated positioning, controlled in precise form through a personal computer (PC) located inside the chamber. An external PC carries out the automation of the experiments using a control software that also allows to visualize the temperature mapping inside the phantom. The measurement of the temperature is carried out with a precision of ±0.2°C in the interval of 35°C at 45°C. The sensors positioning system has a resolution of 2.5 mm and a load capacity of 3 kg. The control and visualization software presents a friendly interface for the user. According to the tests carried out until the moment with this thermometry system, we can conclude that the obtained results are satisfactory.**

***Keywords* – optical fiber, hyperthermia, radiofrequency, ultrasound, temperature measurement.**

## I. INTRODUCTION

The normal temperature of the human body varies in an interval from 35.1ºC to 37.7ºC, although under pathological conditions the temperatures can rise to higher values, even arriving up to 42ºC [1]. In oncology therapeutic treatments, the cancerous cells can be destroyed if a controlled heating is induced with temperatures from 6ºC to 8ºC for up of the normal temperature of the body [2]. The hyperthermia consists on raising in a controlled way the temperature of certain region of the body in the interval from 42ºC to 46ºC for the clinical cancer treatment [3]. The healthy cells heated to these temperatures don't have such a marked sensibility, and a higher fraction of cells survives. This is the basis of the use of the hyperthermia in cancer therapies [4].

Much of the benefit that is coming from hyperthermia depends in a critical way on the ability to induce and to measure high temperatures locally. The heating is carried out via local irradiation of energy, mainly by means of ultrasonic or electromagnetic waves. To be able to manage the irradiation parameters it is necessary to know the temperature to which the radiated tissue rises, that makes practically indispensable to have a highly reliable system of temperature measurement.

The measurement of temperatures is carried out with thermometry systems that can be invasive [5]-[7], or non invasive [8], [9]. The use of the conventional sensors (RTD, thermistors, thermocouples, etc.) it's not satisfactory in some applications, just as it is the case of the therapies for hyperthermia with microwaves. This is due to that currents and voltages are induced by electromagnetic interference in the metallic elements and a self-heating by induction appears. Both factors produce erroneous readings as a result in the measurements when using these sensors [10].

When these conditions are presented it is necessary to build sensors denominated as non-perturbators of the electromagnetic field, like those based on optical fibers. Among them we find the fluorescent sensors [11], the interferometric sensors [12], those based on the variation of intensity caused by absorption or reflection [13] and the evanescent sensors [14].

At the present time, there are in the world diverse laboratories dedicated to the experimental investigation of the hyperthermia, where the electromagnetic radiation is used inside a controlled and safety ambient. In the Section of Bioelectronics of the CINVESTAV-IPN there is an automated laboratory, in which controlled radiation experiments with microwaves are carried out in the interval from 4 GHz to 8 GHz and pulsating wave ultrasound at 1 MHz. This radiation has an impact on a biological tissue substitute material (phantom), where heating is obtained by the interaction of radiation with the radiated material. The experiments are carried out inside an anechoic chamber to avoid the external electromagnetic interferences and at the liberation of the energy radiation to the environment [15].

The thermometry system that is described is part of this automated laboratory. This system measures the temperature inside the phantom, which is heated through the electromagnetic and ultrasonic fields radiations that are being carried out.

## II. METHODOLOGY

The system can be divided in four parts: the stage of temperature measurement using optical fiber sensors and the analog signal conditioning; the stage of automated positioning of the temperature sensors inside the phantom; the communication and control stage using two personal computers; and a general software for the visualization of the temperature distribution inside the phantom. Fig. 1 shows a block diagram of the system.

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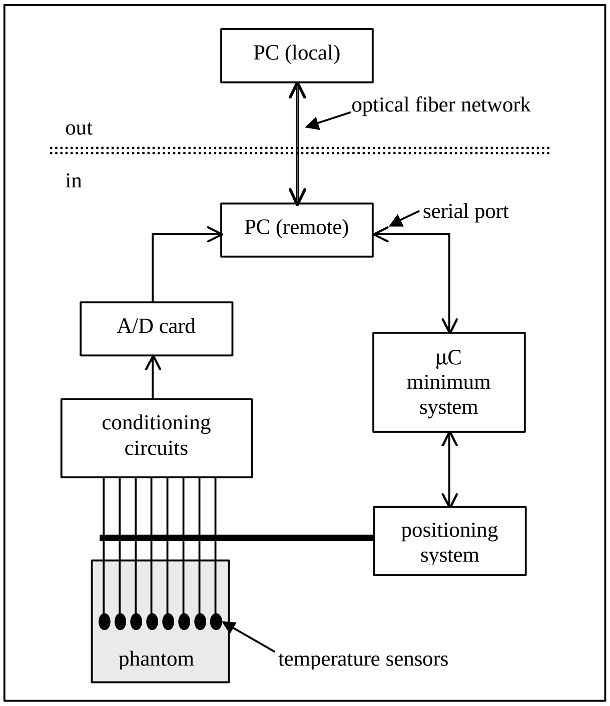


Fig. 1. Block diagram of the thermometry system. µC: microcontroller; out: anechoic chamber outside; in: anechoic chamber inside.

### A. Temperature sensor and signal conditioning

The sensor measures the temperature based on the variations of optical power caused by the replacement of the optical fiber cladding by a material that changes its refraction index with the temperature [16]. A LED with a wave longitude of 880 nm and an aperture angle of 5º was used as emitting element. The used optical fibers are of the plastic type, because their low cost and the easiness of building connectors of their diameter (0.5 mm). To replace the optical cladding raw oil of linseed was used, which is biologically compatible, thinking of a future application on human beings. To encapsulate the oil a thin walled glass tube was used, sealed with epoxy in both ends. In the fig. 2 an outline of the built sensor is shown.

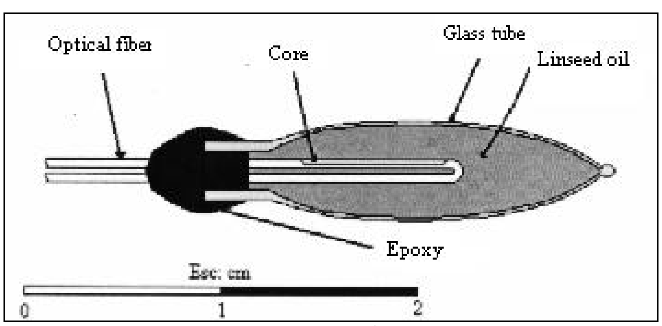


Fig. 2. Schematic outline of the built sensor.

The fluctuations obtained in the optical receiver are owed mainly to the variations of power that the sensor generates when detecting the changes of temperature. This is due to that the optical transmitter offers a great stability, thanks to the use of the optical feedback technique. This consists on detecting the variations of the optical power that emits the transmitter using a phototransistor and to provide a compensation of it. To be able to carry out the optic feedback a special connector was built, which contains the emitting LED, the phototransistor and a spherical lens of 8 mm. The spherical lens was used to inject a bigger optic power to the fiber. To hold the optic fiber, the special connector was built of Teflon. The LED that was selected as optic source is the PDI-E805-ND, and the photodetector used to carry out the feedback it is the NTE3032 phototransistor.

A receiving circuit was used to be able to detect the variation of the optical power taken place by the sensor, which converts it in a proportional voltage signal. As optoelectronic device to transform the optical power into an electric signal the NTE3032 phototransistor was used.

Eight temperature sensors and conditioning circuits were built in order to guarantee a measurement in several points, what allowed to know the distribution of temperature in a plane of the phantom.

### B. Positioning stage

This stage is constituted basically by a personal computer (PC), a microcontroller based minimum system and a PC controlled automated positioning system [15].

The PC is IBM compatible. It sends the data that correspond to a position selected by the user toward the minimum system. This PC is located inside the anechoic chamber and it is externally teleoperated through an optical fiber communication system. The communication between the PC and the minimum system is carried out through the communications port COM1.

The minimum system is based on the Motorola´s M68HC11F1 microcontroller. This makes the sweeping of the temperature sensors and indicates to the PC the time in which the temperature sensors are in position so that this makes the corresponding reading. When the PC has captured the data coming from the sensors, this in turn indicates to the minimum system that can continue. With this instruction the minimum system displaces the temperature sensors toward the following point where the measurement of temperature should be carried out. These actions repeat successively until it has covered completely the wanted area. In each action, the temperature sensors collect data; these data are acquired and processed in each point. The group of these data indicates the temperature distribution in the phantom. The temperature sensors are displaced in an axis through the phantom by means of an automated positioning system. Two DC motors controlled by the minimum system by means of the feedback signal that provides an optical encoder impel this. The maximum lineal travel distance is of 35 cm, with a resolution of 2.5 mm. The physical construction of the positioning system is built on a square

base of acrylic of 65 x 120 cm of external area, of 1 cm thick. Bars of Nylamid were also used for support. The used materials minimize the interaction with the electromagnetic fields that could be present. In the fig. 3 an outline of the positioning stage is shown.

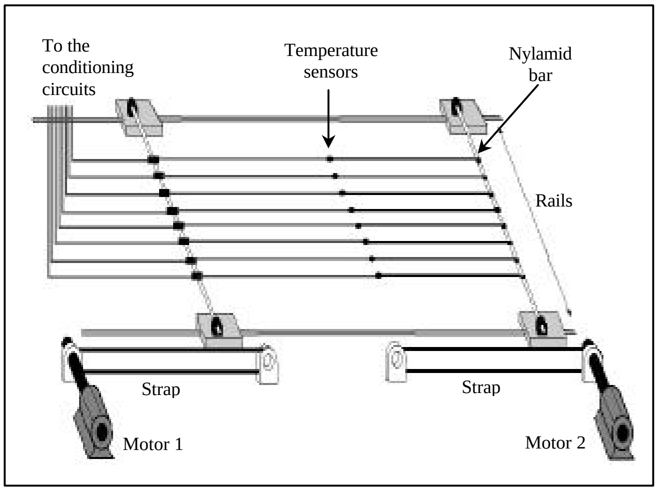


Fig. 3. Schematic outline of the positioning stage.

### C. Communication and control stage

The communication system is based on the use of two IBM compatible computers, one of them inside the anechoic chamber (remote) and the other one in the exterior (local). The communication among both computers was carried out through an optical fiber cable; the local PC teleoperates the remote PC. The local PC controls all the equipment inside the chamber and captures all the acquired information.

An optical fiber based net card was used to communicate the two computers (3C905B-FX(SC), 3Com 100Base-FX). It possesses a speed of transmission of 100 Mbps. The protocol used to communicate both computers was the TCP/IP. The package used for the communication was the Remote Administrator v2.0, which allows to control all the devices and programs of the remote computer from the local computer.

The analog signals coming from the eight conditioning circuits were digitized by means of a 12 bits analog to digital card (Lab PC-1200 A/I, National Instruments) that is installed in the remote computer.

### D. Visualization and control software

A software was developed in the LabWindows CVI programming language (National Instruments). By means of this software the user can control all the controllable devices that conform the automated laboratory. Data like the radiation time and frequency, the distance between the radiator and the phantom, the quantity of temperature measurements in a plane of the phantom, the quantity of phantom mappings, the sensor thermal response time, the elapsed time between each temperature mapping, among other, should be provided by the user.

Once the experiment begins, the laboratory operates automatically and allows the user to visualize the results obtained in each temperature mapping. In the fig. 4 the main screen of the program is shown.

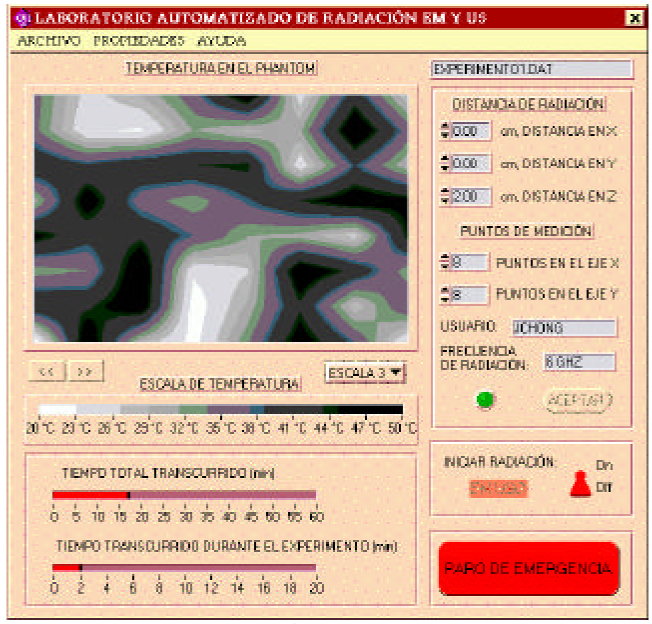


Fig. 4. Software main screen.

## III. Results

The optical fiber thermometers were calibrated and characterized with precision instruments in the thermo metrics laboratory of the Superior School of Physics and Mathematics of the National Polytechnic Institute. For the eight analyzed circuits a precision of ±0.2°C was obtained in the interval of interest (35°C at 45°C). The curve of static calibration is shown in fig. 5. The sensor's thermal response time, for a 30°C to 50°C temperature step change, was of 30 seconds.

In the positioning stage, the repeatability and precision of the displacements of the positioning system, the stage of power and the signal conditioning circuits were evaluated. The developed system is able to locate the temperature sensors with 2.5 mm of spatial resolution. The system has a capacity of load of 3 kg., what is more than enough for the required application.

The control and visualization software was evaluated carrying out each one of the functions for those that it was designed. Errors were not presented in the execution of the commands that the software is able to carry out. The way in that the program displays the numeric information and the map of the temperature inside the phantom was subjected to the evaluation of diverse experts.

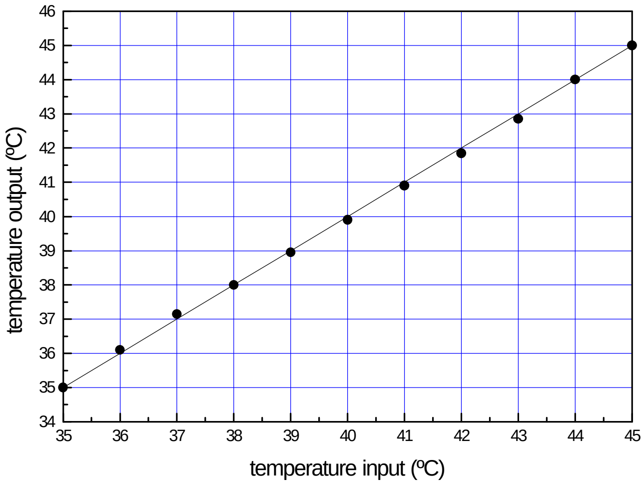

Fig. 5. Static calibration curve of the temperature measuring circuit.

## V. Conclusion

According to the tests carried out until the moment with the thermometry system, we can conclude that the obtained results are satisfactory.

The developed optical fiber sensors offer to the system the possibility to measure the temperature in a material substitute of biologic tissue subjected to electromagnetic radiation without causing interferences. The materials used for their construction are biocompatible, what represents an advantage if one thinks of a future application on human beings.

The value of precision obtained in the calibration process of the temperature measurement stage grants a level of acceptable confidence to the system. However, the value of the thermal time constant is inconvenient when the measurements want to be carried out fast. This can be solved diminishing the thermal inertia of the sensor sheath material, whenever the same one continues fulfilling the characteristic of not perturbing the electromagnetic fields.

The system of automated positioning presented repetitive and precise movements, inside the appropriate limits for the application. The materials used for their construction didn't present interferences in the electromagnetic field.

In the evaluation of the capabilities of the control and visualization software, satisfactory results were obtained under operation conditions, although still left carry out validation tests according to the corresponding standards. The program introduced a user-friendly graphic interface, according to the expert’s evaluation, that which facilitates the operation of this system like integral part of the hyperthermia laboratory.

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